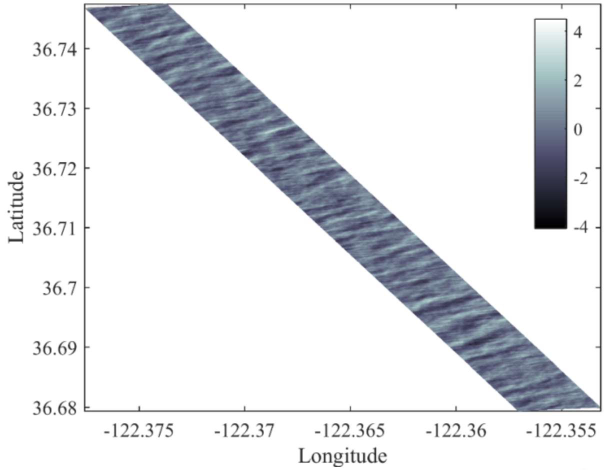
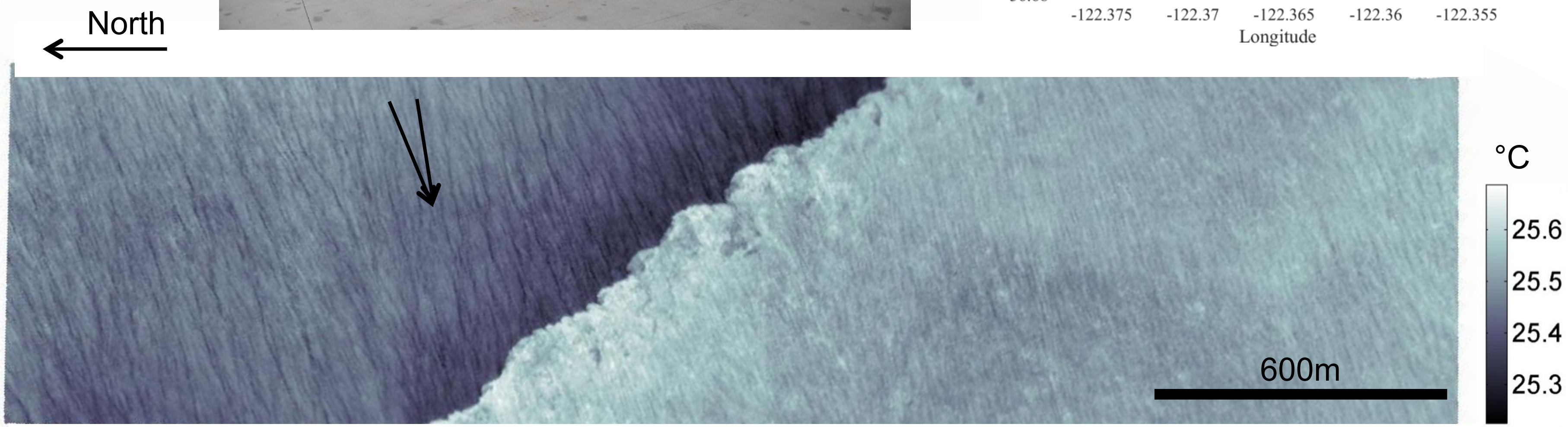
# Airborne Lidar Measurements in Ocean Topography

Ken Melville, Luc Lenain
Scripps Institution of Oceanography




*Airborne infrared imagery showing a temperature front at the northern boundary of the Loop Current*

# Background

We have been making airborne lidar measurements for more than a decade to measure ocean surface wave directional spectra for air-sea interaction and coastal research

During a 2004 experiment in the Gulf of Tehuantepec we used along-track SSHA to estimate cross-track geostrophic velocities.

In a 2011 experiment in the Gulf of Mexico there were coincident Jason-1 overflights so we flew along-track to test the lidar against satellite altimetry with some success (See below).

Microwave scattering from the ocean surface depends directly on the surface wave field at least from scales of the radar wavelength to larger scales and indirectly on the wind field

- Ka band (27-40GHz, 1.1 – 0.75 cm)

Altimetric averages and wavenumber spectra over areal data will depend on the directional spectra of the surface and internal wave fields.

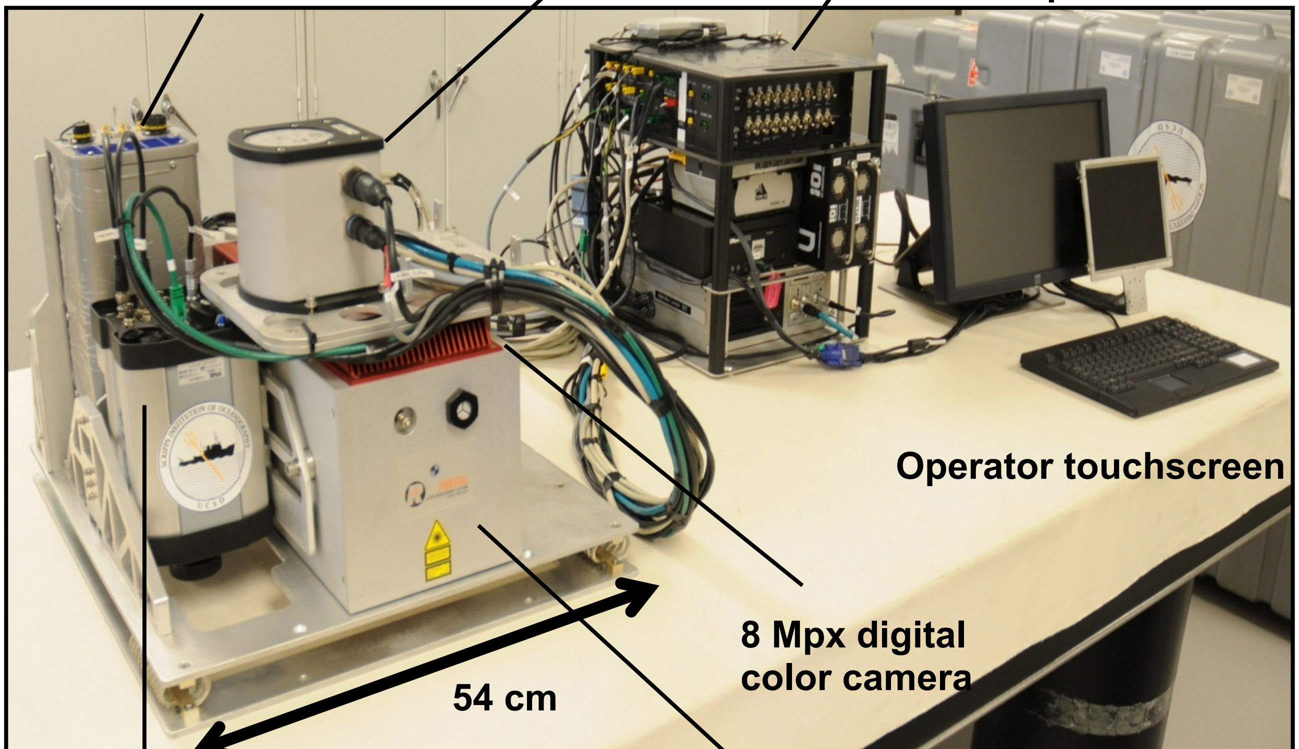
# SIO Modular Aerial Sensing System (MASS)



Hyperspectral (Specim EagleAISA)

GPS/IMU (NovAtel LN200 SPAN)

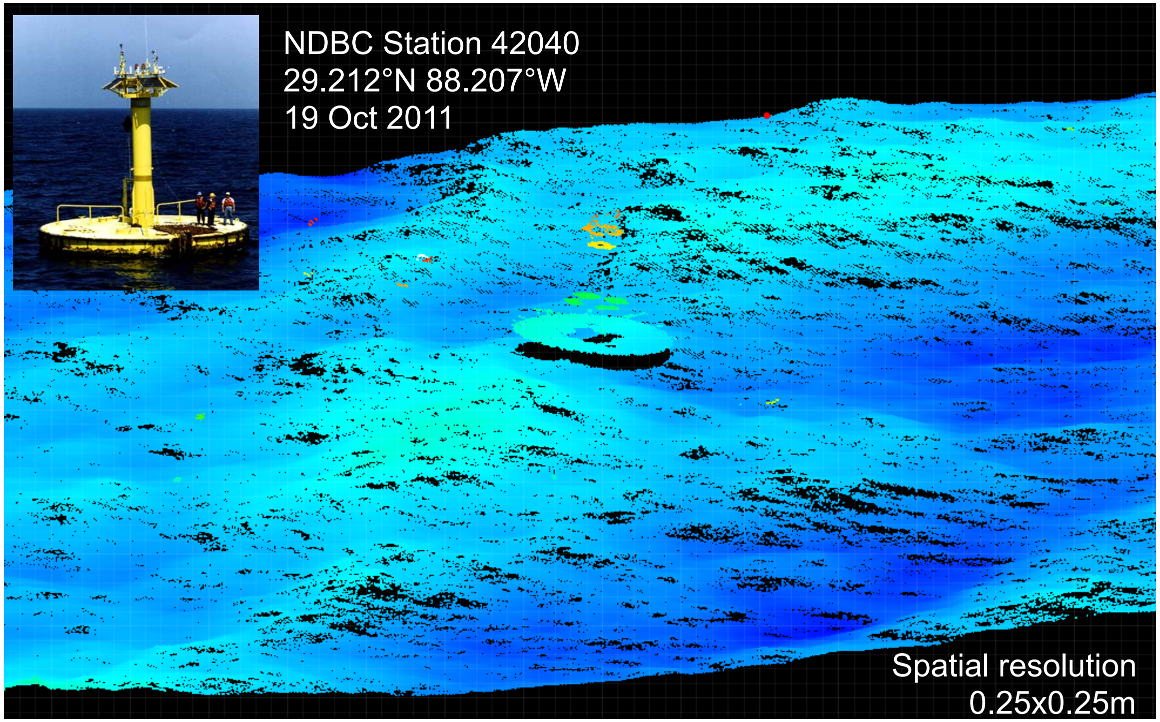
Power distribution, synchronization, data acquisition




Long Wave IR Camera (FLIR SC6000 LWIR)

Scanning waveform lidar (RIEGL Q680i)

# SIO Modular Aerial Sensing System (MASS)

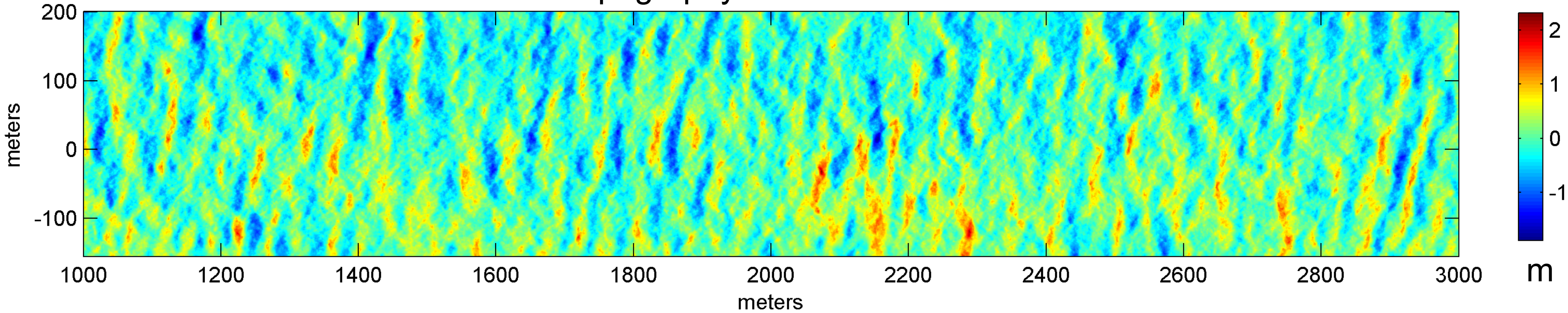



*Example of surface elevation as measured from the MASS during a 2011 experiment in the Gulf of Mexico, flying above NDBC buoy #42040. (wind~12m/s, Hs = 3.1m)*

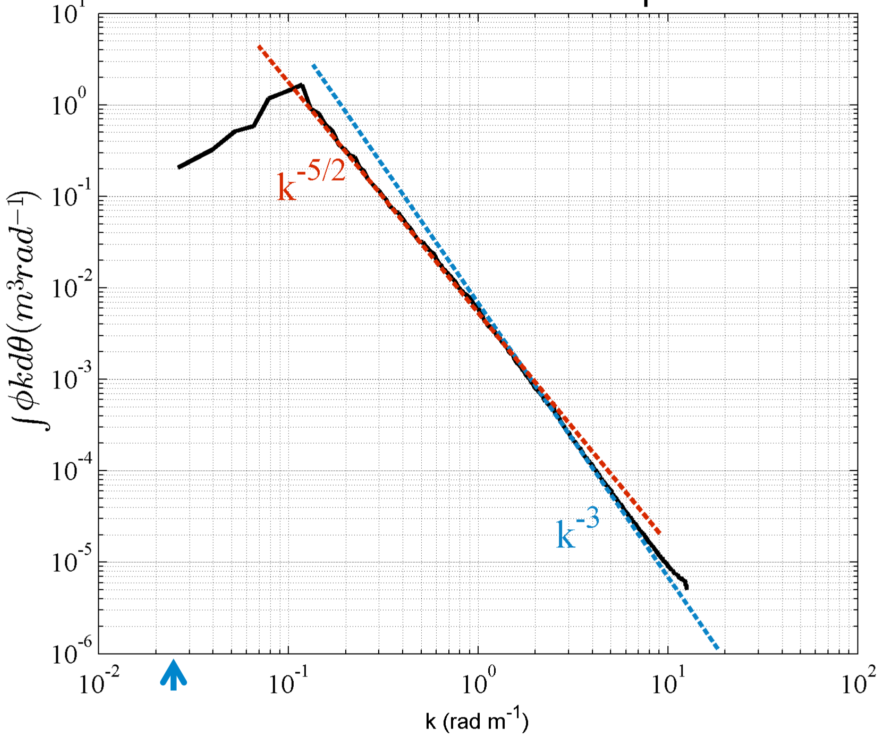
| **Instrumentation** | | **Measurement** |
|---|---|---|
| Scanning Waveform Lidar wave | Riegl Q680i | SSH, Surface wave, surface slope, directional spectra (vert. accuracy ~2-3cm) |
| Long-wave IR Camera | FLIR SC6000 (QWIP) | Ocean surface processes, wave kinematics and breaking, frontal processes |
| High-Resolution Video | JaiPulnix AB-800CL | Ocean surface processes, wave kinematics and breaking, frontal processes |
| Hyperspectral Camera | Specim EagleAISA | Ocean surface and biogeochemical processes |
| GPS/IMU Novatel SPAN-LN200 | | Georeferencing, trajectory |

# Surface Waves Measured by the MASS Lidar

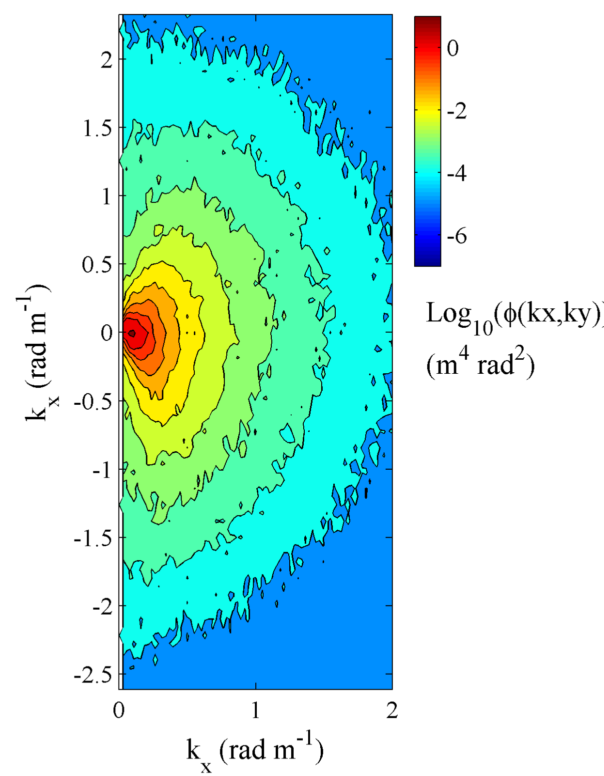
Sea surface topography collected from the MASS lidar




Omnidirectional wavenumber spectrum

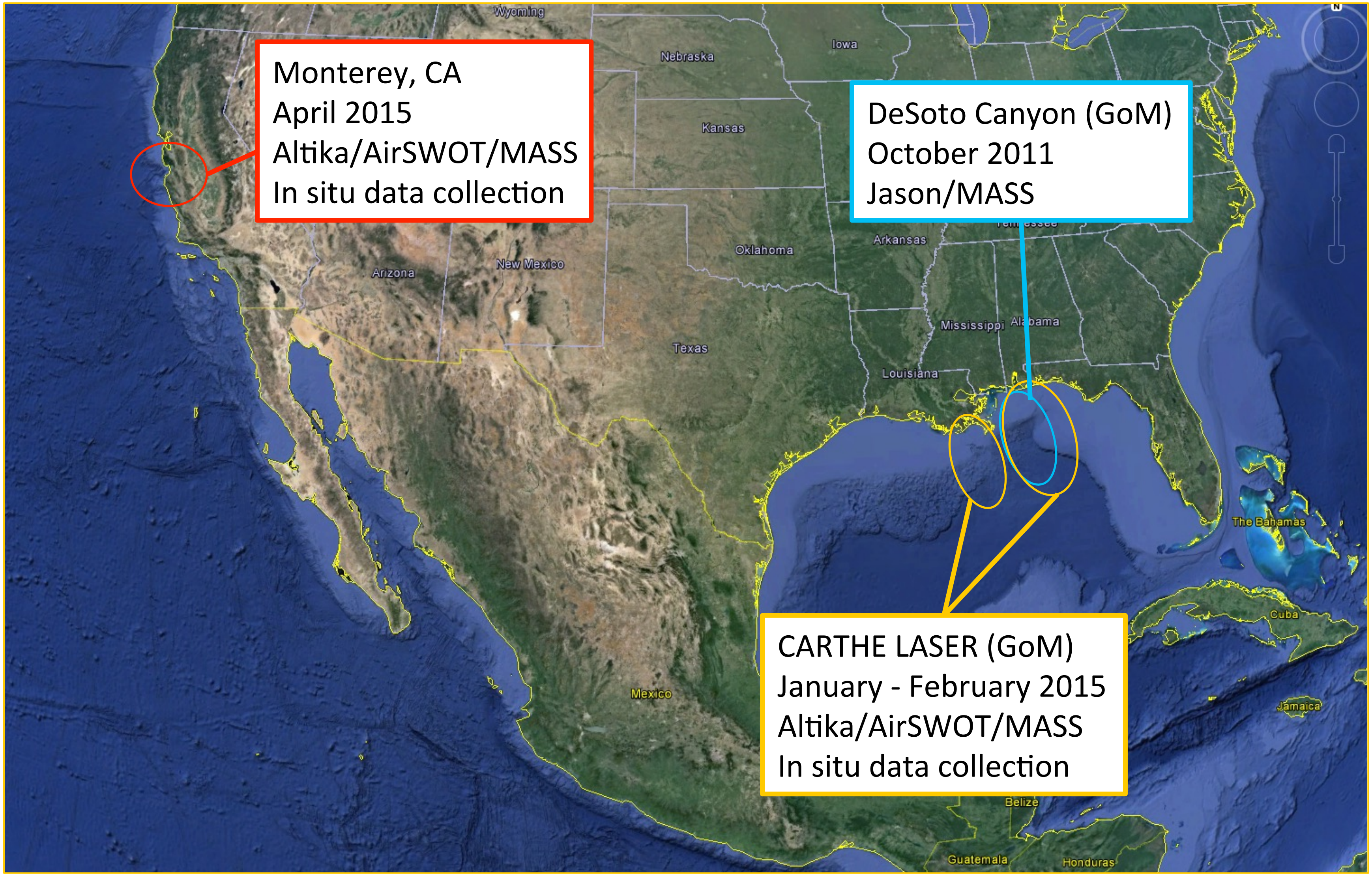



directional wavenumber spectrum



# Ocean topography campaigns - Overview





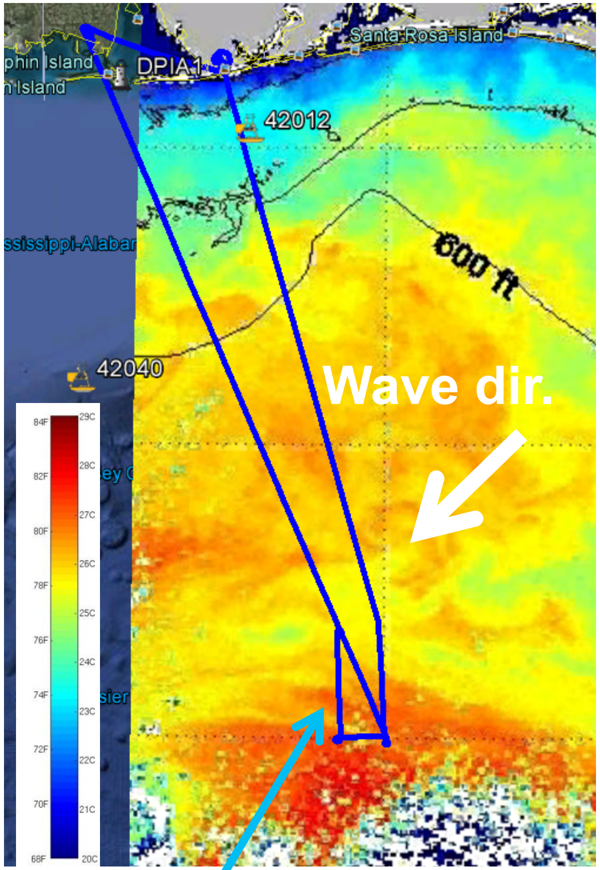

Monterey, CA
April 2015
Altika/AirSWOT/MASS
In situ data collection

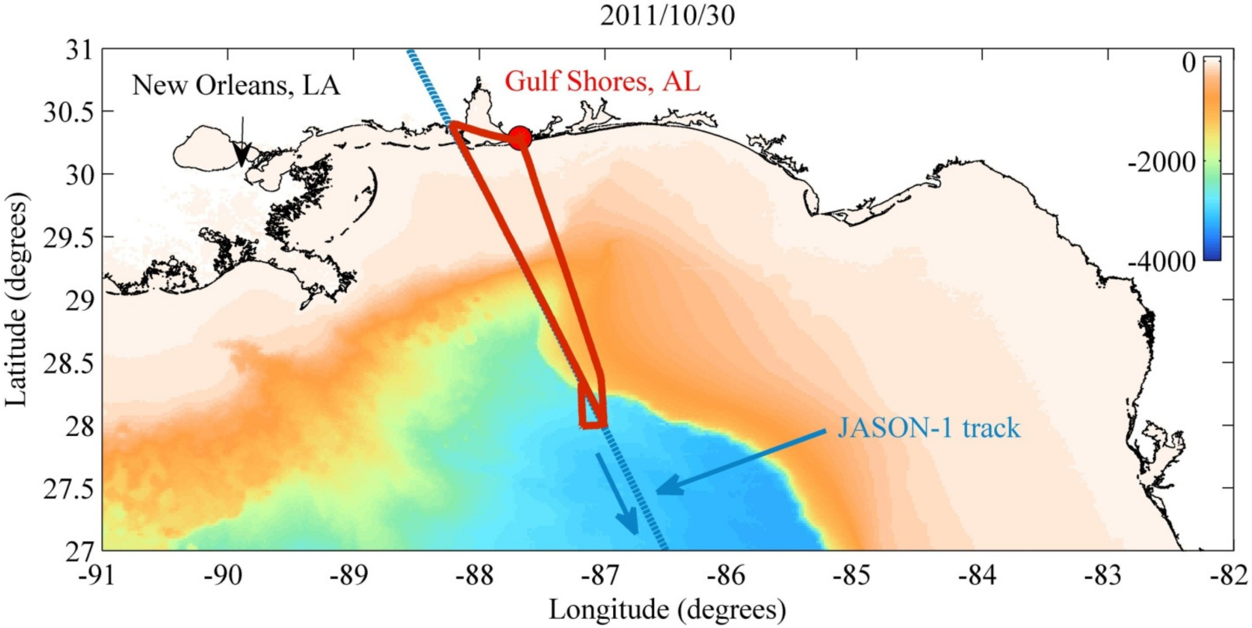
DeSoto Canyon (GoM)
October 2011
Jason/MASS

CARTHE LASER (GoM)
January - February 2015
Altika/AirSWOT/MASS
In situ data collection

# The Gulf of Mexico Experiment – October 2011
# Coincident MASS flight and Jason-I satellite overpass

AVHRR NOAA-19
October 30 2011 08:04 GMT

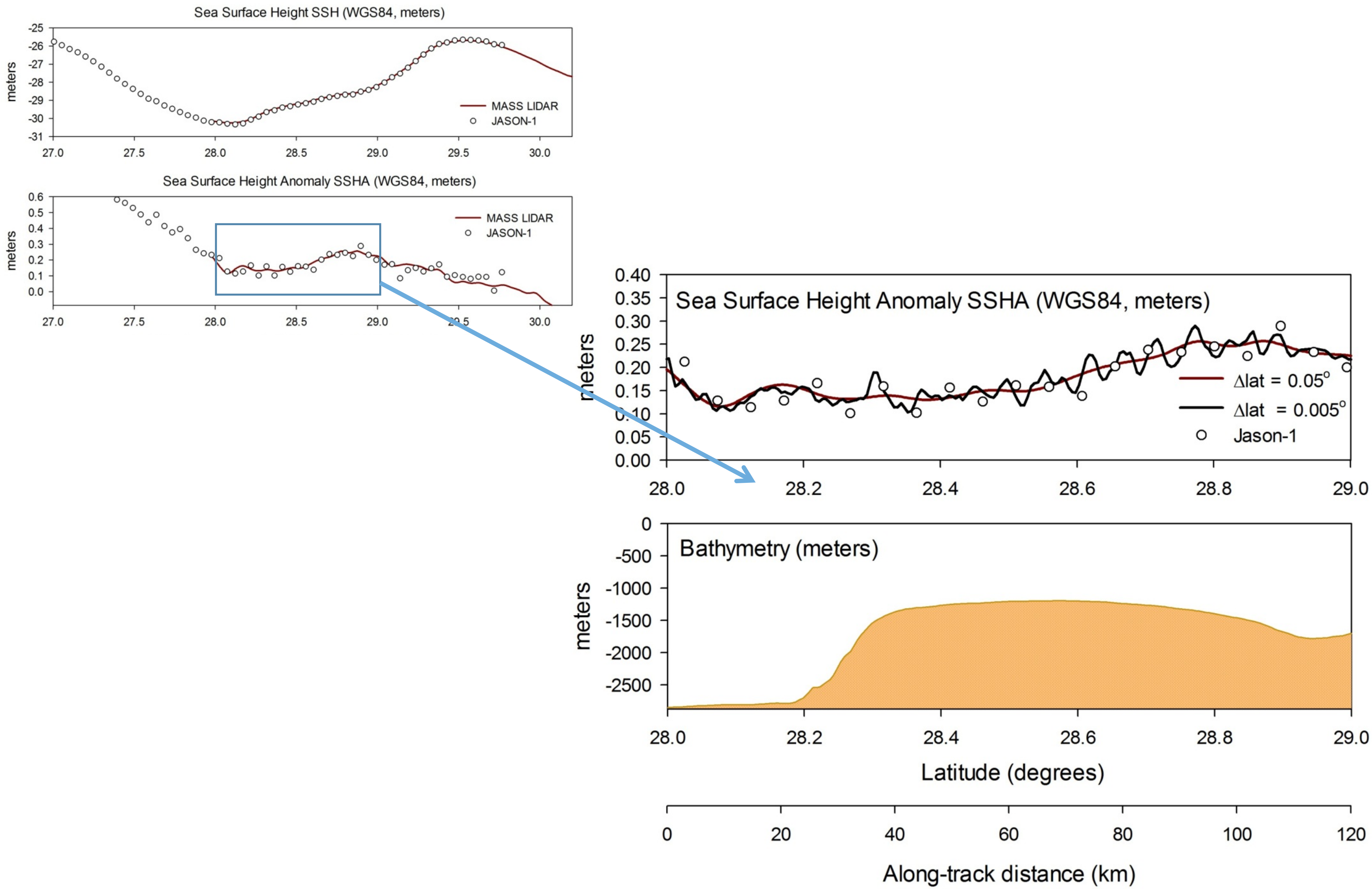


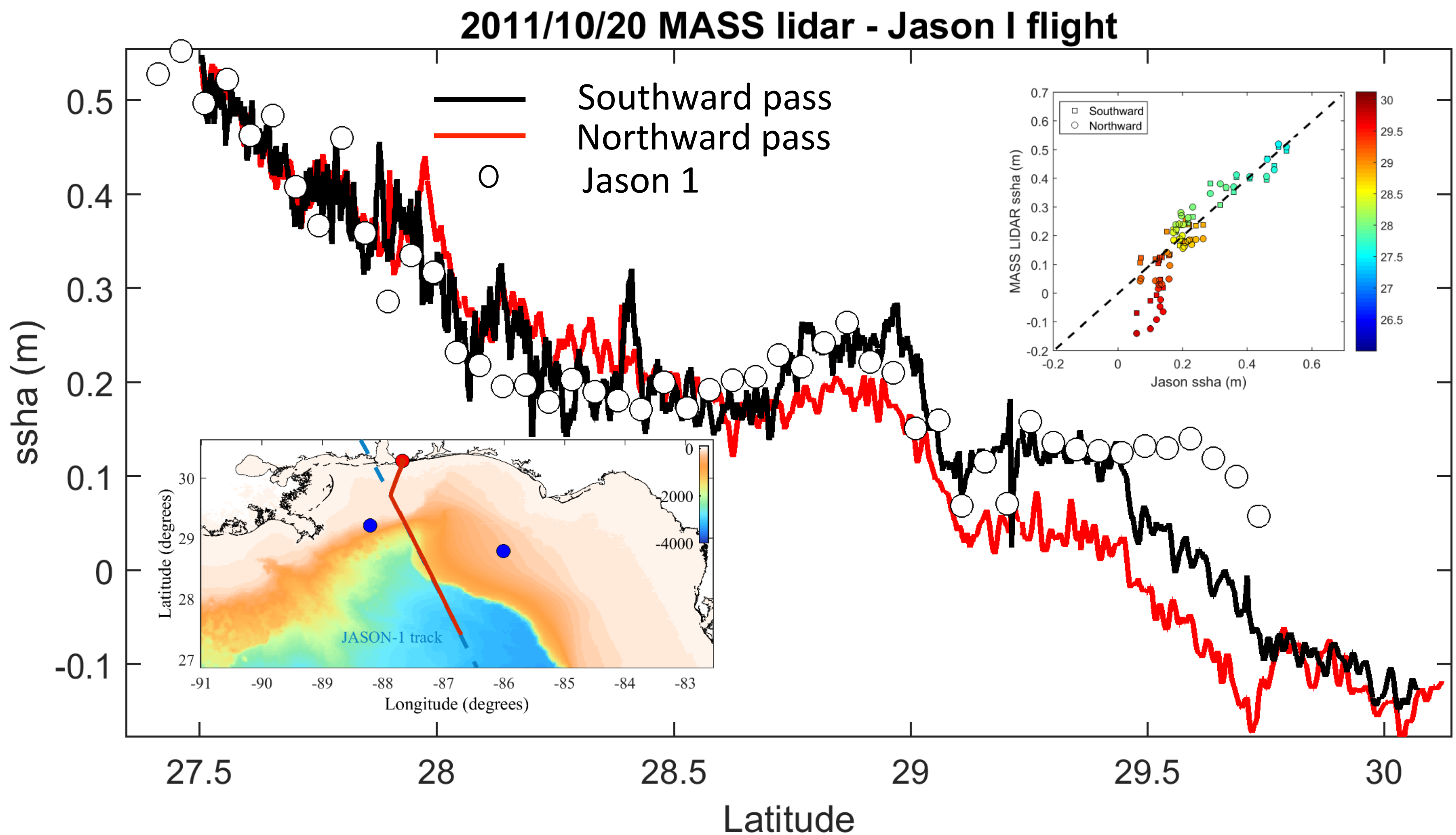




Flight track on 2011/10/30
Enhanced breaking & SST front

# High-Resolution SSHA from Airborne Altimetry

SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego

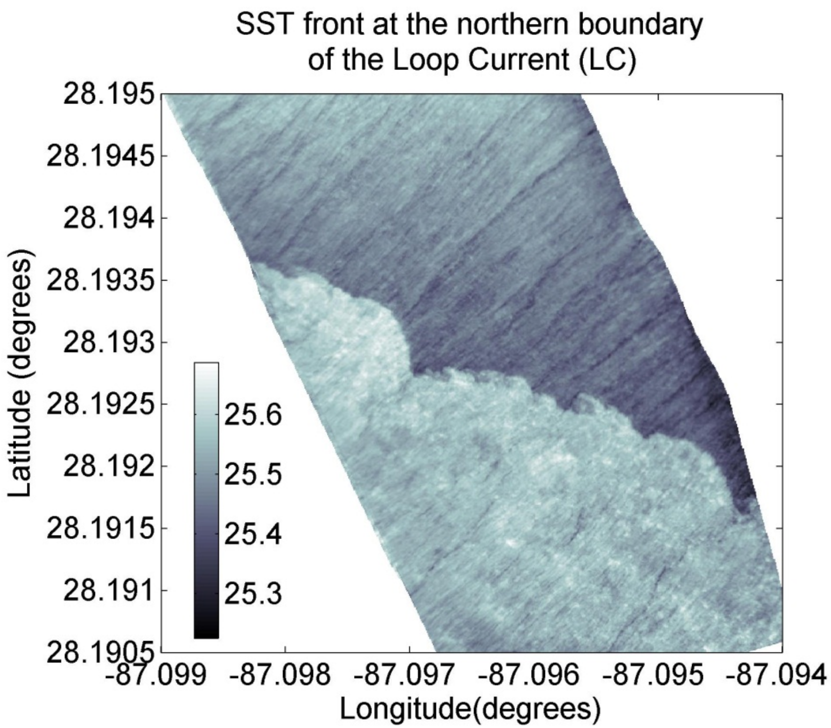




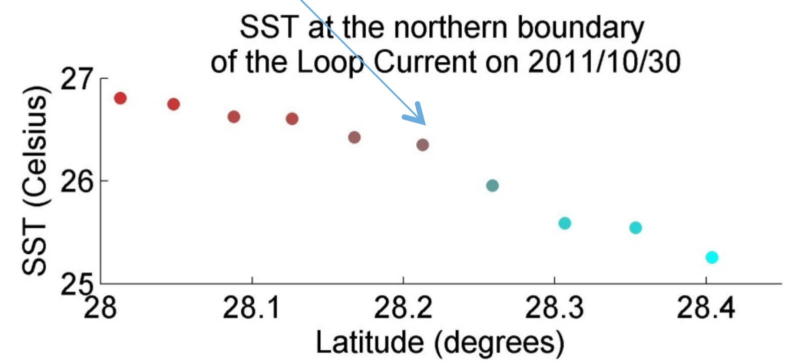

SSHA estimated from two MASS lidar passes ("northward" and "southward") over the same Jason-I track (see insert). Note that the satellite pass occurred in the middle of the southward lidar pass (black).

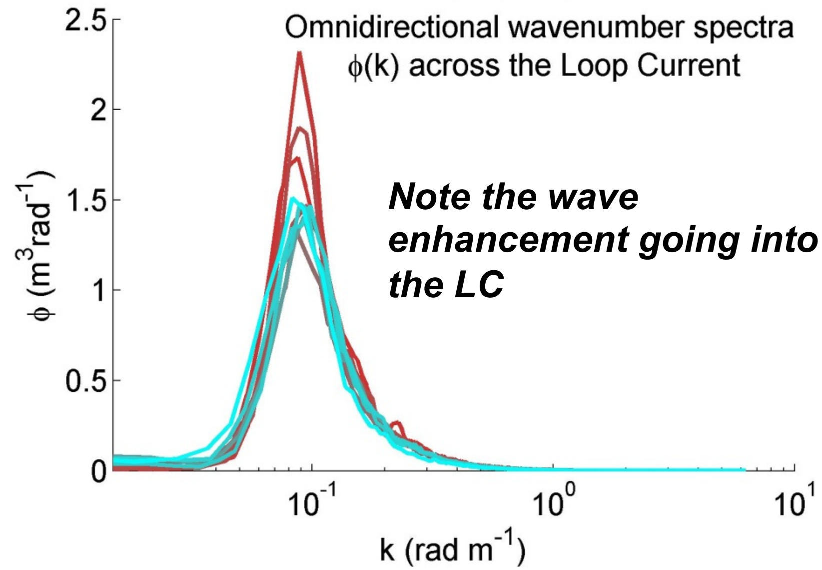
# Wave Enhancement at SST Front

SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego




Northern edge of the LC

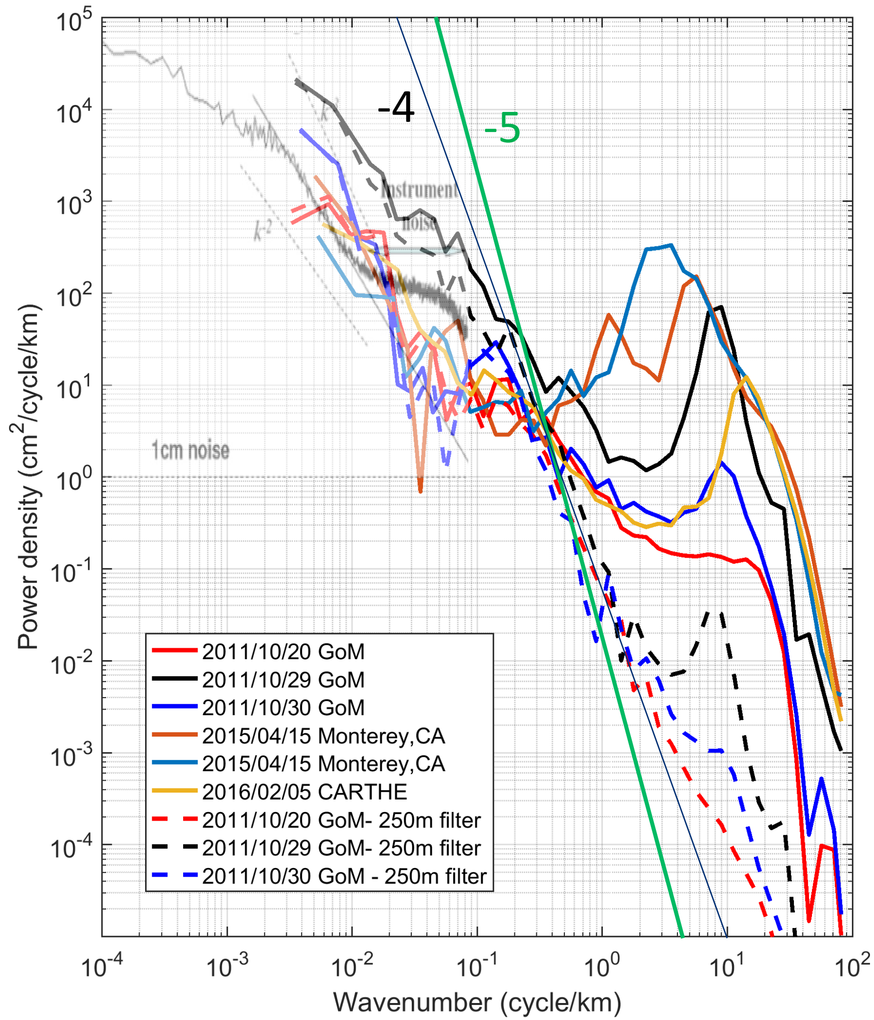



(left) Sea surface temperature imagery of the northern edge of the Gulf of Mexico Loop Current on October 30 2011. (right) Evolution of the omnidirectional wavenumber spectrum as the aircraft flew across the Loop Current . The color scale represents the average SST over the length of the wave record (4 km) used in the spectral analysis, also shown as a function of latitude in the upper panel.

# SSHA spectra

SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego

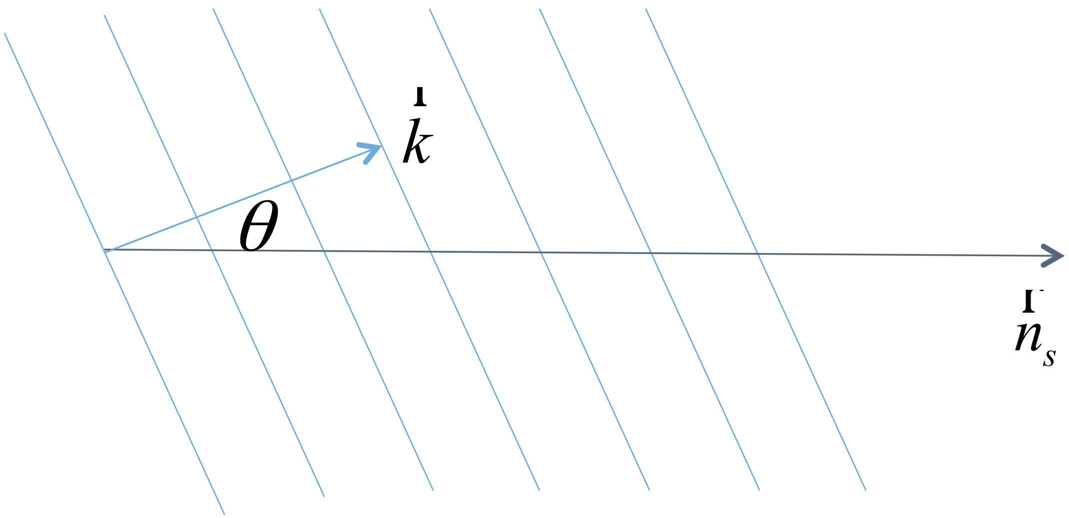



*SSHA spectra measured by three flights of the scanning lidar along a descending Jason-1 track in the Gulf of Mexico (October 2011), Altika track off Monterey Bay (April 2015) and during CARTHE (February 2016). The data are plotted over satellite altimeter data from Figure 1 of Fu & Ferrari (2008), noting the O(100)km resolution of the traditional satellite altimeters.*

# Aliasing of Waves into longer Wavelengths

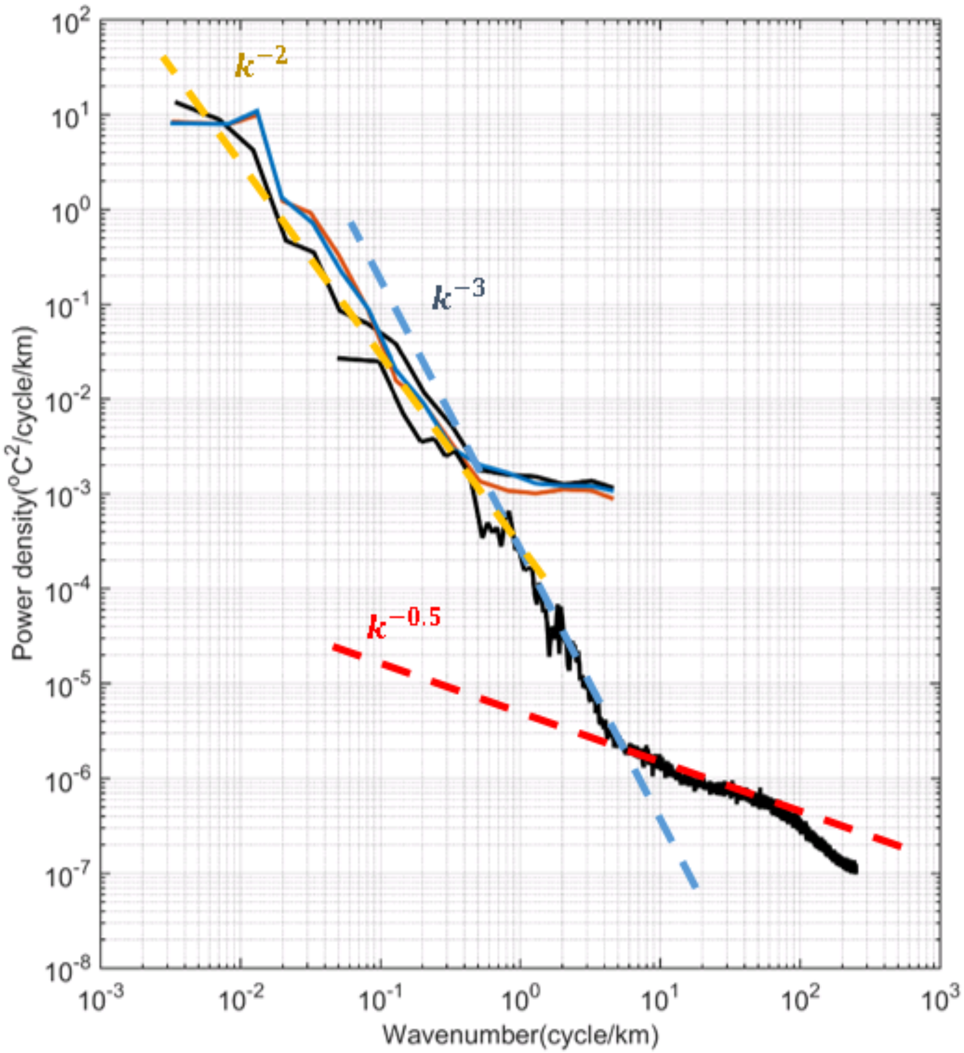


If the wave field is given by $\eta \propto e^{i(\vec{k}.\vec{x}-\omega t)}$, where $\left|\vec{k}\right| \equiv k = \lambda / 2\pi$, and the unit vector along the satellite track is $\vec{n}_s$, then the measured wavelength along the satellite track $\lambda_s = \frac{\lambda k}{\vec{k}.\vec{n}_s} = \frac{\lambda}{\cos\theta}$. That is the waves will be aliased into lower wavenumbers.



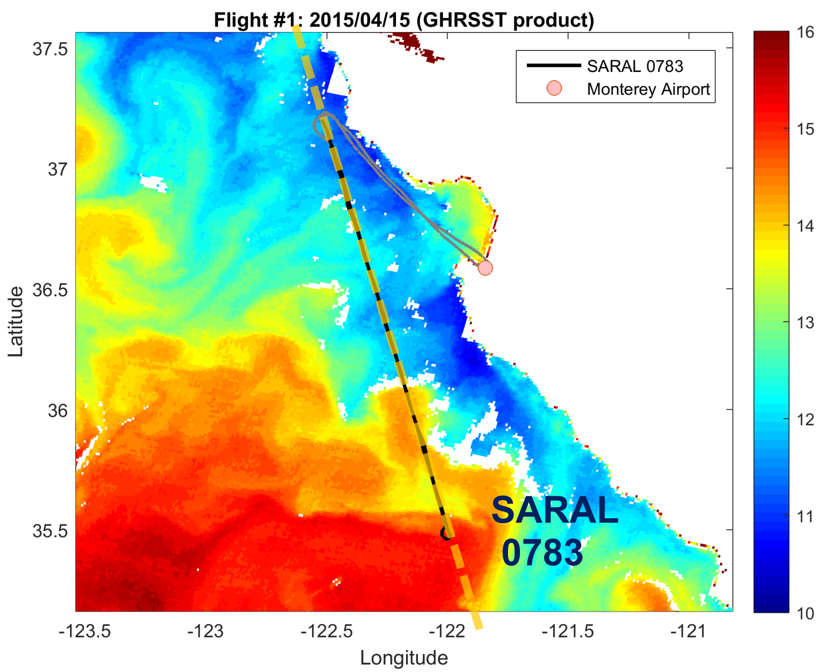
# SST wavenumber spectra (KT19 and IR imagery)

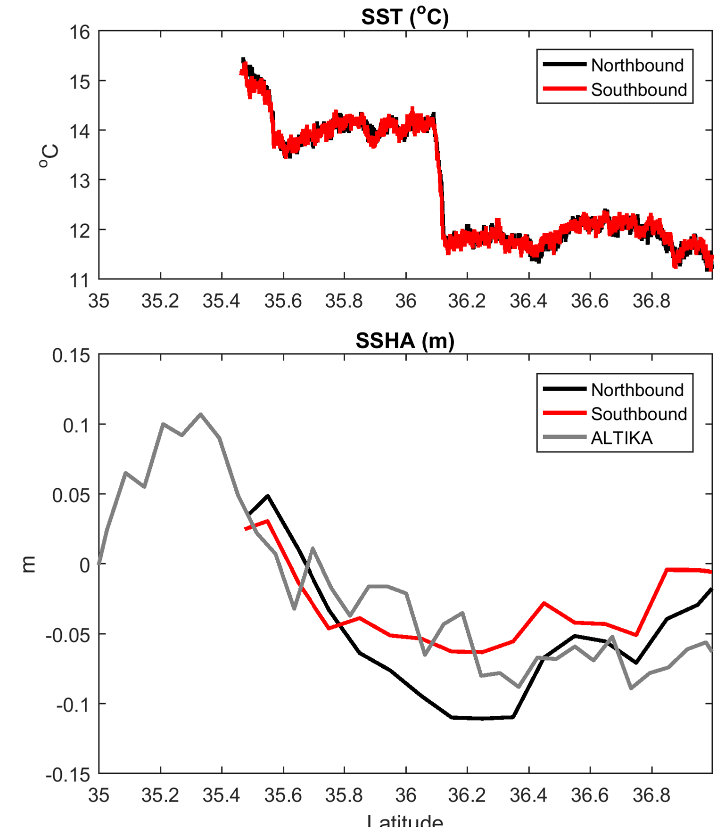




# April 15 2015 – SARAL 0783 overflight -SSHA

SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego




Data source:
20150415180103-OSISAF-L2P_GHRSST-SSTsubskin-AVHRR_SST_METOP_A-sstmgr_metop02_20150415_180103-v02.0-fv01.0.nc

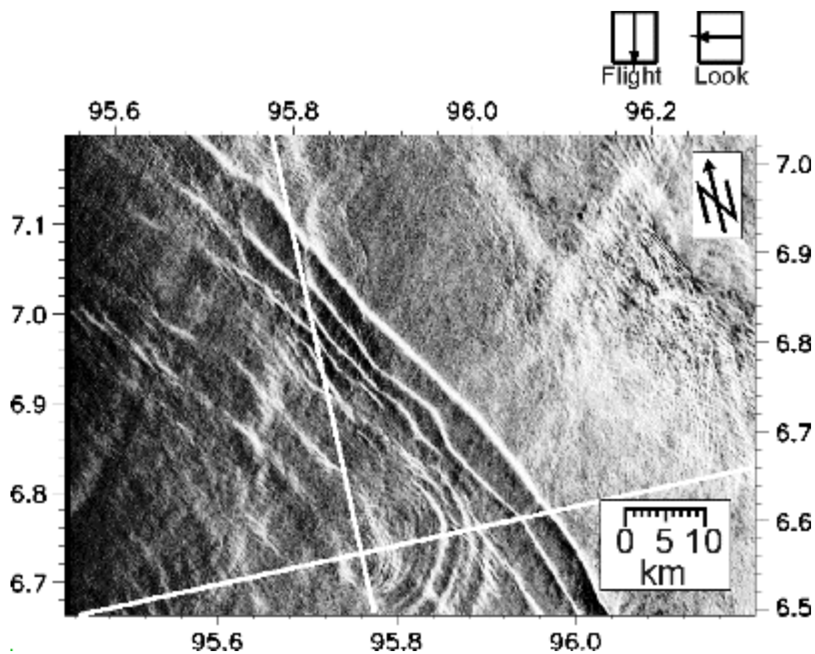
(provided by L. Marie' – IFREMER)

**SST SATELLITE DATA collected ~ <u>4hrs</u> after end of the research flight**

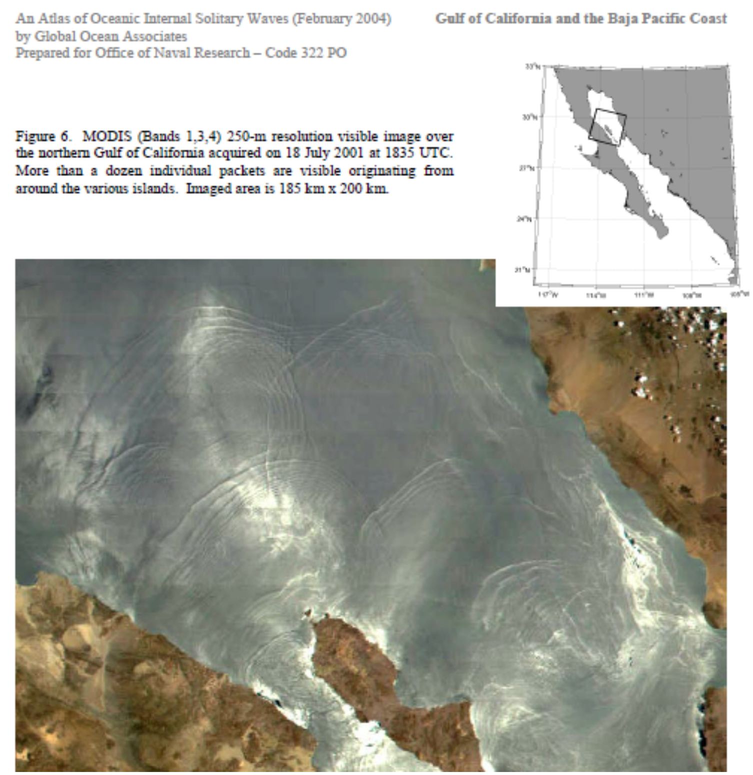
- Clear skies, $H_s$ =3.2-4 m, $U_{10} = 10\ m/s$
- SARAL-0783 overflight time: 13:42-13:47 (UTC
- SIO aircraft on "station": 13:20 to 14:50 (UTC)

# Nonlinear Internal Waves

Nonlinear internal waves associated with tidal forcing are ubiquitous in coastal oceans and marginal seas. They may have very long crests O(100) km and wavelengths O(10) km, with large heights O(10-100) m that give rise to forced surface waves O(1-10) cm height. These may not average out in a 60 km swath and would also alias into longer wavelengths.




SAR image Andaman Sea (Alpers et al. 2014)



# Conclusions



Airborne lidar , along with radiometric and IR imaging for SST, appears to provide basic spectral measurements at scales that are relevant for mesoscale and submesoscale ocean dynamics.

The lidar also provides directional measurements of the surface wave field that are required to quantify the aliasing of the surface waves into the longer wavelengths.

The current instrument/aircraft system yields swath widths in the range 300-600 m over distances of approximately 900 km. A faster longer-range aircraft is desirable to extend range out to 2000 km or more.

More work is needed on taking out the errors in the tides in shallow water and in estimating other errors, including those associated with atmospheric corrections affecting GPS.

We expect airborne lidar to be valuable contributor to the science and Cal/Val phase of SWOT.